Utah Geological Survey Open-File Report 443DM
Interim Geologic Map of the Lower San Juan River Area,
Eastern Glen Canyon National Recreation Area and Vicinity,
San Juan County, Utah

UTAH GEOLOGICAL SURVEY

UTAH GEOLOGICAL SURVEY
a division of
Department of Natural Resources

in cooperation with the National Park Service

Utah Geological Survey Open-File Report 443DM
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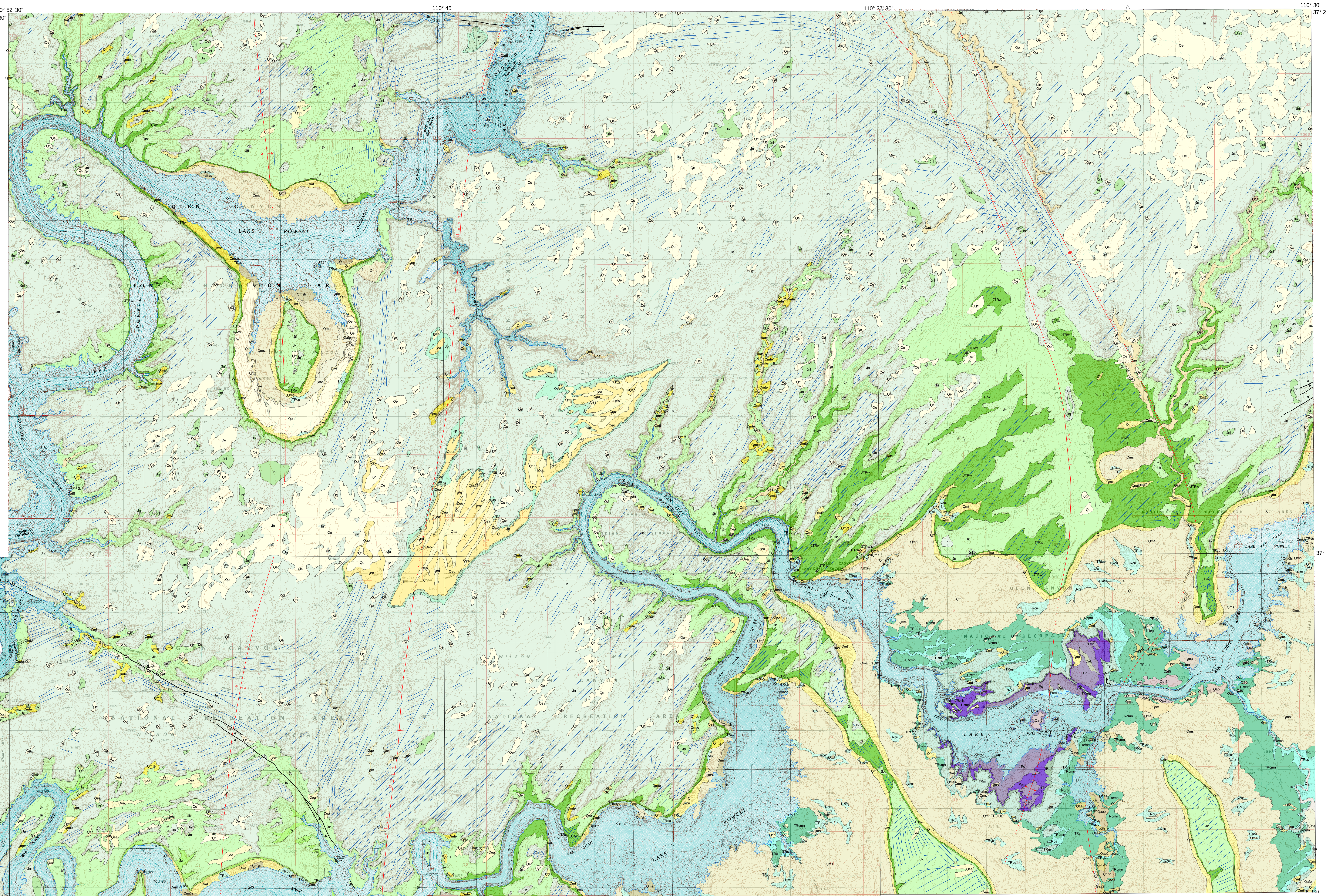
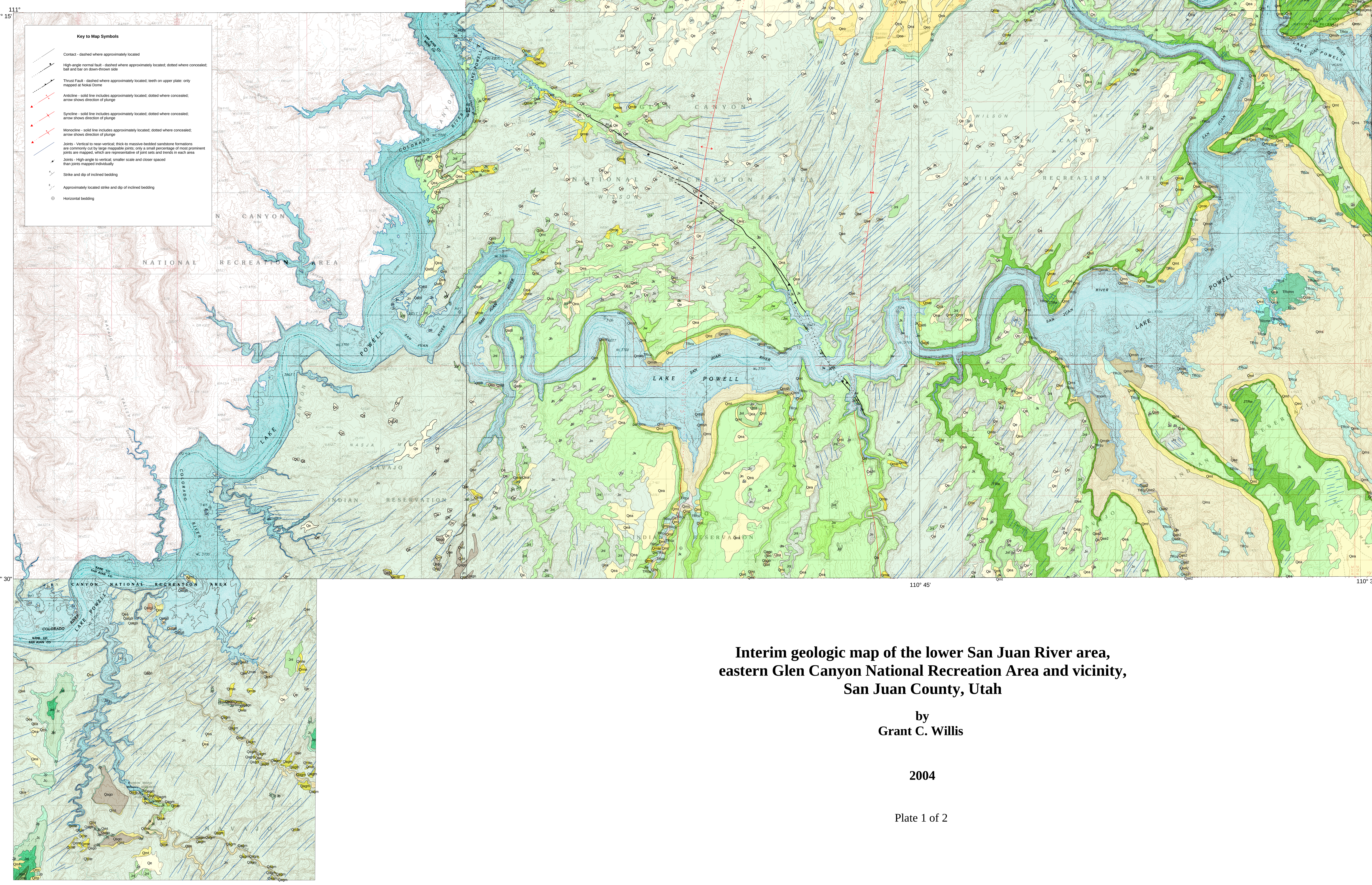
This geologic map was funded by the Utah Geological Survey and the National Park Service. The views and conclusions contained in this document are those of the author and should not be interpreted as necessarily representing the official policies, either expressed or implied, of the U.S. Government.

Scale 1:50,000

Key to Map Symbols

Contact - dashed where approximately located

High-angle normal fault - dashed where approximately located; dotted where concealed; ball and bar on down-thrown side

Thrust Fault - dashed where approximately located; teeth on upper plate: only mapped at Nokai Dome

Anticline - solid line includes approximately located; dotted where concealed; arrow shows direction of plunge

Syncline - solid line includes approximately located; dotted where concealed; arrow shows direction of plunge

Monocline - solid line includes approximately located; dotted where concealed; arrow shows direction of plunge

Joints - Vertical to near-vertical; thick-to massive-bedded sandstone formations are commonly cut by large mappable joints; only a small percentage of most prominent joints are mapped, which are representative of joint sets and trends in each area

Joints - High-angle to vertical; smaller scale and closer spaced than joints mapped individually

Strike and dip of inclined bedding

Approximately located strike and dip of inclined bedding

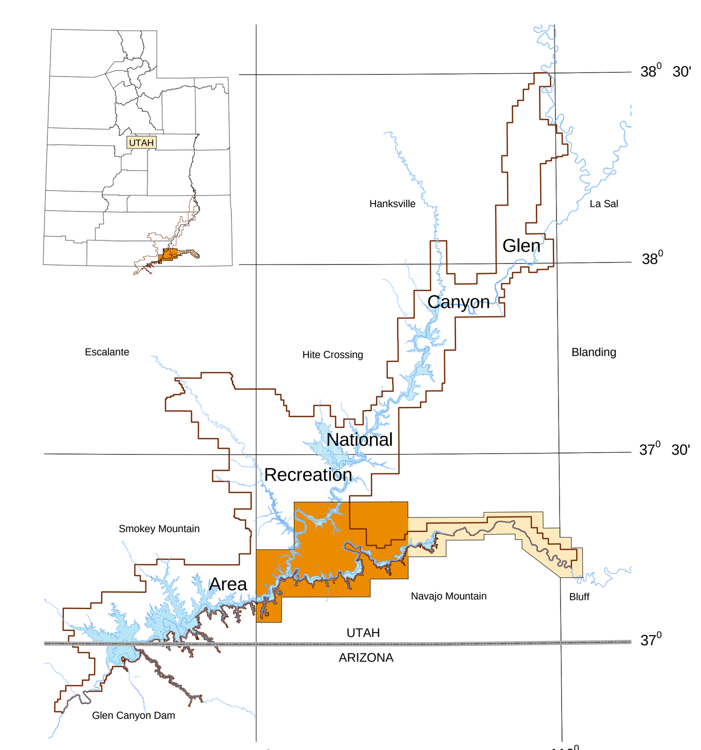
Horizontal bedding

Interim geologic map of the lower San Juan River area, eastern Glen Canyon National Recreation Area and vicinity, San Juan County, Utah

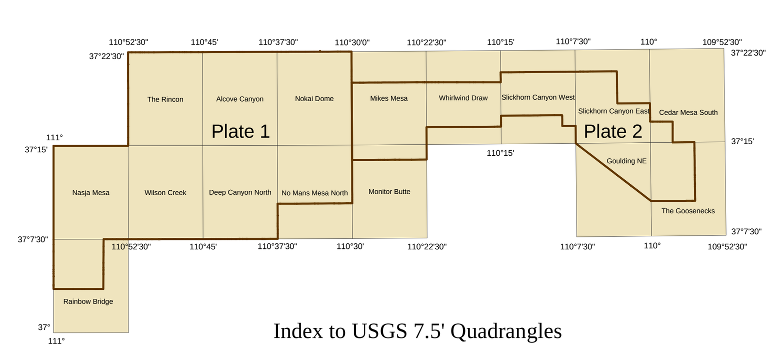
by
Grant C. Willis

2004

Plate 1 of 2



Index to USGS 30' x 60' Quadrangles



Index to USGS 7.5' Quadrangles

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Interim geologic map of the lower San Juan River area, eastern Glen Canyon National Recreation Area and vicinity, San Juan County, Utah

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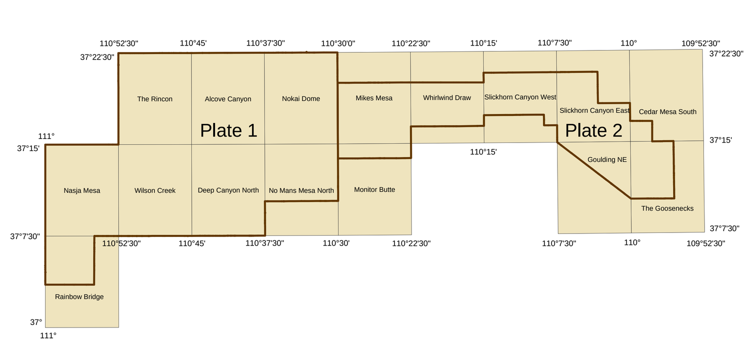
Plate 2 of 2



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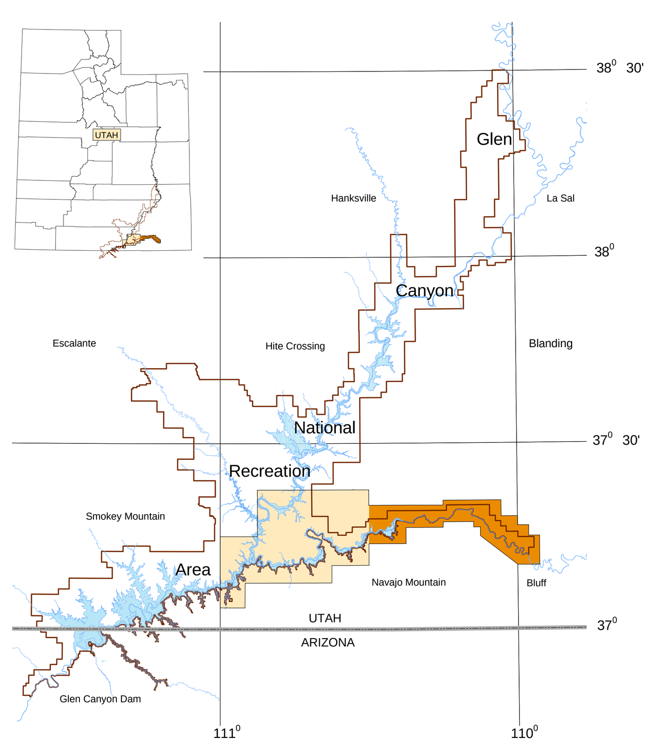

Index to USGS 30' x 60' Quadrangles

Scale 1:50,000

0 0.5 1 2 3 4 Miles

0 0.5 1 2 3 4 5 Kilometers

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Description of Map Units

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Quaternary

Artificial Fill

Qf Artificial fill (Historical) — Small dikes and dams emplaced to create stock-watering ponds; 0 to 30 feet (0-9 m) thick.

Alluvial-dominated Deposits

Qa Alluvial deposits (Holocene) — Boulder to pebble gravel, sand, silt, and clay deposited in small drainages; varies from poorly to moderately well sorted; locally includes large angular boulders from rock falls, landslides, and debris flows; clast composition reflects local lithologies; similar in composition and setting to Qae deposits except eolian component is minor because intermittent stream flow has removed or reworked most eolian material; includes deposits in active part of wash and up to about 20 feet (6 m) above wash floor; 0 to 20 feet (0-6 m) thick.

Qal_1 Younger alluvial deposits (Upper Holocene) — Interbedded gravel, sand, silt, and clay deposited by the San Juan and Colorado Rivers; generally moderately to well sorted; clasts are well rounded to subrounded and uniformly sized with most less than 6 inches (15 cm) in diameter — San Juan River clasts are slightly larger on average than Colorado River clasts; small scale trough cross-bedding, climbing ripple laminations, and imbricated cobbles are common; locally includes poorly sorted debris flow deposits and rock fall debris derived from side canyons and cliffs; forms sand and gravel bars in river channel and small remnants on steep canyon slopes up to 45 feet (14 m) above the modern river; 0 to 30 feet (0-9 m) thick; carbonized plant fragments collected from an unlithified silt and sand bed about 40 feet (12 m) above the San Juan River yielded a calendar-corrected ^{14}C age of 2220 ± 40 B.P.

Qat_2 to Qat_{12} Alluvial river terrace deposits (age discussed below) — Moderately to well-sorted cobble to pebble gravel and sand with minor silt and clay; form terrace remnants on benches and slopes near the San Juan and Colorado Rivers; commonly armored by clean gravel lag; generally includes minor talus and colluvial debris from adjacent bedrock units; as mapped includes reworked terrace deposits that drape downslope from the original terrace deposits where the terraces are being eroded; present up to 930 feet (280 m) above the modern river channels; numbers denote relative heights above the modern channel (larger mapped deposits locally include deposits of more than one level — their assigned number is based on the height of the main part of the deposit); 0 to 30 feet (0-9 m) thick. Not all levels are preserved in this map area.

$Qate_2$ to $Qate_{12}$ Alluvial river terrace deposits with eolian mantle (age discussed below) —

Similar to Qat deposits described above but widely mantled by eolian sand and silt.
$Qatg_2$ to $Qatg_{12}$ Alluvial river terrace deposits with older alluvial gravel (age discussed below) — Similar to Qat deposits described above but a major component is large boulders (as described in Qago) incorporated into terrace deposits along the Colorado River.

Elevation and Estimated Age of Terrace Deposits

Rare volcanic ash beds, basalt flows, strath terrace and pediment deposits, and other dateable materials in surficial deposits in the Colorado River basin provide a means to calculate average regional incision rates of the major rivers (table 1). These rates vary significantly, raising considerable uncertainty about the calculated incision rates. When applied to the heights of river terrace deposits above adjacent rivers, the rates provide an estimate of ages of terrace and correlative deposits. However, the terrace ages are only considered rough estimates because the calculated rates vary over a broad range, dateable materials are rare, some data come from sites over 100 miles (160 km) away, interpretation of data is commonly debatable, and incision rates probably varied over time. I believe data supporting the lower rates are more reliable pending additional information. I use 0.66 feet (0.20 m) per thousand years for assigning series and age designations in table 2. Short-term cut-and-fill cyclicity of rivers probably also significantly skews estimated ages of younger low-level deposits (for example, some level 2 deposits may be as young as Holocene).

Table 1. Published Calculated Average Incision Rates of the Colorado River and Major Tributaries.

Average calculated incision rate (per 1000 years)	Time interval forming basis for calculation	Location	References
0.79 feet (0.24 m)	3 million years	Glenwood Springs, Colorado	Kirkham and others, 2001; and references cited therein
0.59 feet (0.18 m)	620,000 years	Westwater Canyon, Utah	Willis, 1992, 1994; Willis and Biek, 2001
1.25 to 1.57 feet (0.38-0.48 m)	189,000 years	Fremont River about 80 miles (130 km) upstream of Lake Powell	Marchetti and Cerling, 2001
0.36 feet (0.11 m)	1.4 million years	Bluff about 30 miles (50 km) east of the eastern part of the map area	Wolkowinsky and Granger, 2004
1.64 feet (0.5 m)	500,000 years	Navajo Mtn pediments near Glen Canyon	Hanks and others, 2001
0.46 feet (0.14 m)	500,000 years	Eastern Grand Canyon	Pederson and others, 2002
1.31 feet (0.4 m)	500,000 years	Eastern Grand Canyon	Davis and others, 2001
1.02 to 1.64 (0.31-0.5 m)	600,000 years	Eastern Grand Canyon	Lucchitta and others, 2001

Table 2. Estimated ages of river terraces based on height of terraces above river and average incision rates discussed above.

Level	Height above river feet (meters)	Estimated ages using low and high long-term incision rates low: 0.2 meters/ky ka=thousand years BP	high: 0.5 meters/ky Ma=million years BP	Series/Age (based on low rate)
2	40-90 (12-27)	long-term rates probably don't apply due to short-term cut-and-fill cyclicity		Holocene to Upper Pleistocene
3	90-140 (27-43)	135ka-215ka	54ka-86ka	Upper to Middle Pleistocene
4	140-210 (43-64)	230ka-320ka	86ka-130ka	Middle Pleistocene
5	210-290 (64-88)	320ka-440ka	130ka-180ka	Middle Pleistocene
6	290-380 (88-120)	440ka-600ka	180ka-240ka	Middle Pleistocene
7	380-430 (120-130)	600ka-650ka	240ka-260ka	Middle Pleistocene
8	430-550 (130-170)	650ka-850ka	260ka-340ka	Mid. to Low. Pleist.
9	550-670 (170-200)	850ka-1.0Ma	340ka-400ka	Lower Pleistocene
10	670-730 (200-220)	1.0Ma-1.1Ma	400ka-440ka	Lower Pleistocene
11	730-830 (220-250)	1.1Ma-1.3Ma	440ka-500ka	Lower Pleistocene
12	830-930 (250-280)	1.3Ma-1.4Ma	250ka-560ka	Lower Pleistocene

Qagm Intermediate alluvial gravel deposits (Upper to Middle Pleistocene) — Poorly to moderately sorted boulder to cobble gravel with varying amounts of sand, silt, and clay; clasts are mostly angular to subrounded, well-silicified sandstone and conglomerate boulders up to 6 feet (2 m) in diameter; many clasts were derived from the Jurassic Morrison Formation, and most have a dark-brown weathering patina that gives deposits a dark-brown to brownish-black color; consist of terrace-like remnants of alluvium and debris flow materials deposited in channels draining the flanks of Navajo Mountain; probably mostly reworked from Qago deposits; generally on benches and slopes 20 to 100 feet (6-30 m) above the floor of small streams and washes, but still within the canyons; 0 to 30 feet (0-9 m) thick.

Qago Older alluvial gravel deposits (Middle to Lower Pleistocene) — Similar to Qagm deposits described above, but form pediment like mantle over sloping benches, and commonly have thick pedogenic carbonate accumulation in upper part of deposit; consist of remnants of alluvial pediment mantle and debris flow deposits that probably once formed an alluvial-fan apron around the flanks of Navajo Mountain; cap high, gently sloping benches and knolls up to about 1400 feet (430 m) above the floor of adjacent small streams and washes; 0 to 60 feet (0-18 m) thick; Hanks and others (2001) reported ages of 0.5 to 0.78 million years on these deposits, projected these surfaces to a higher ancestral river up to 1400 feet (430) above the modern Colorado River, and then used these surfaces to calculate an average incision rate of 1.64 feet (0.5 m) per thousand years (see discussion above). This rate is higher than most other rates discussed above, raising the question if these surfaces were ever graded to the ancestral river.

Qaf Alluvial-fan deposits (Holocene) — Poorly to moderately sorted large-boulder to clay-sized sediment; angular to subangular clasts; deposited in areas where gradients decrease along and at the mouths of small drainages; deposited mostly by debris flows; clasts generally decrease in size down slope; 0 to 30 feet (0-9 m) thick.

Qafe Alluvial-fan deposits with eolian mantle (Holocene to Upper Pleistocene) — Similar to alluvial-fan deposits described above, but blanketed with windblown sand and silt; 0 to 30 feet (0-9 m) thick.

Qae Alluvial and eolian deposits (Holocene) — Boulder to pebble gravel, sand, silt, and clay deposited in small drainages, mixed with windblown sand and silt; poorly to moderately sorted; locally include large angular boulders from rock falls, landslides, and debris flows; clast composition reflects local lithologies; similar in composition and setting to Qa and Qac deposits except has larger eolian component, especially in areas protected from active erosion; includes deposits in active part of wash and up to about 40 feet (12 m) above wash floor; 0 to 20 feet (0-6 m) thick.

Qae_2 Level-2 alluvial and eolian deposits (Holocene) — Similar in composition and setting to some Qae deposits; differentiated where levels are large enough to be mappable at this scale; incised by actives washes forming inactive terraces and benches 20 to 40 feet (6-12 m) above adjacent wash; generally has eolian mantle since upper surface is isolated from most alluvial erosion; 0 to 20 feet (0-6 m) thick.

Qae_3 Level-3 alluvial and eolian deposits (Holocene to Upper Pleistocene) — Similar in composition and setting to Qae_2 deposits except forms inactive terraces and benches 40 to 80 feet (12-24 m) above adjacent wash and generally has larger eolian component; 0 to 20 feet (0-6 m) thick.

Qaeo Older alluvial and eolian deposits (Holocene to Upper Pleistocene) — Similar to Qae deposits except incised by active washes forming inactive terraces and remnants on benches 30 to more than 100 feet (9-30+ m) above the wash; partially equivalent to Qae_2 and Qae_3 deposits except not as strongly terraced; some deposits armor low ridges or form erosional remnants; in some areas not clearly related to adjacent washes; 0 to 80 feet (0-24 m) thick.

Qac Alluvial and colluvial deposits (Holocene) — Moderately to poorly sorted large-boulder to clay-sized sediment deposited on low to moderate slopes and in small drainages; locally mixed with windblown sand and silt; includes ephemeral stream deposits and colluvium derived from adjacent slopes; locally includes large angular boulders from rock falls, landslides, and debris flows; clast composition reflects local lithologies; similar in composition and setting to Qa and Qae deposits except has larger colluvial component; includes deposits in active part of wash and up to about 20 feet (6 m) above wash floor; 0 to 20 feet (0-6 m) thick.

Qaco Older alluvial and colluvial deposits (Holocene to Upper Pleistocene) — Similar in composition and setting to Qac deposits except incised by active washes forming inactive terraces and benches 20 feet to more than 100 feet (6-30+ m) above the wash; 0 to 20 feet (0-6 m) thick.

Eolian-dominated Deposits

Qe Eolian sand (Holocene to Middle? Pleistocene) — Well- to very well sorted, well-rounded sand with minor silt deposited by wind; forms poorly to well developed dunes, mounds, and sheet-like deposits in depressions and areas protected from erosion for long periods of time; locally slightly reworked by alluvial processes and burrowing animals; mostly derived from and present on upper surface of Navajo Sandstone; residual lag of underlying rock is common; 0 to 50 feet (0-15 m) thick.

Qeo Older eolian sand, silt, and carbonate deposits (Holocene to Lower? Pleistocene) — Well- to very well sorted, well-rounded sand and silt deposited by wind, and partially cemented by thick pedogenic carbonate (caliche); carbonate gives outcrops a white to very pale yellowish gray appearance and forms a resistant cap over stabilized eolian and bedrock deposits; unconsolidated deposits are locally stripped off, leaving carbonate "hardpan" bench; locally slightly reworked by alluvial processes and contains local alluvial deposits at base of unit; 0 to 30 feet (0-9 m) thick.

Qea Eolian and alluvial sand and silt (Holocene to Middle? Pleistocene) — Well- to very well sorted, well-rounded sand and silt deposited by wind locally mixed with sand, silt, and fine gravel deposited by alluvial processes; forms poorly developed dunes, mounds, and sheet-like deposits in depressions and areas protected from erosion for long periods of time; similar in setting and composition to Qe deposits except evidence of alluvial activity is more common and dune forms are less developed; mostly derived from and present on upper surface of Navajo Sandstone; residual lag of underlying rock is common; 0 to 50 feet (0-15 m) thick.

Qec Eolian sand and silt and colluvial deposits (Holocene to Upper Pleistocene) — Well- to very well sorted, well-rounded sand and silt deposited by wind, mantling and mixed with locally derived angular boulder to clay-size colluvial sediments; deposited on low-angle slopes; 0 to 30 feet (0-9 m) thick.

Mass-movement Deposits

Qmt Talus deposits (Holocene to Upper Pleistocene) — Very poorly sorted, angular blocks mixed with minor fine-grained materials deposited on steep slopes; composed primarily of accumulated rock-fall debris; commonly includes minor to moderate amounts of eolian sand; 0 to 30 feet (0-9 m) thick.

Qmte Talus deposits and eolian sand (Holocene to Upper Pleistocene) — Similar to Qmt deposits except commonly blanketed by moderate to large amounts of eolian sand that locally completely covers the rock fall debris; 0 to 30 feet (0-9 m) thick.

Qms Landslides and slumps (Holocene to Pleistocene) — Extremely poorly sorted, angular, massive blocks to clay-size material transported downslope as slides, slumps, and earthflows; transported materials vary locally from detached bedrock blocks up to several hundred feet across to surficial deposits that consist of large masses of talus, colluvium, and alluvium; generally forms large coalescing slide masses that extend as a continuous apron up to several miles along outcrop belts; most slip surfaces developed on the Petrified Forest, and to a lesser extent, other members of the Chinle Formation, though also locally present on the Kayenta, Moenkopi, Organ Rock Shale, and other units (the Petrified Forest Member is notorious for contributing to large mass movements throughout southern Utah and surrounding areas); these large landslides and slumps typically form as part of a cyclic process in which weathering and erosion of relatively soft upper members of the Chinle Formation results in undercutting and collapse of the cliff-forming Wingate Sandstone, which then collapses as large slump blocks and rock falls onto the slope-forming Chinle; weathering of weak smectitic clay in the Chinle, aided by precipitation infiltrating the highly fractured collapse debris, triggers additional sliding, which then allows more undercutting of the cliffs; commonly up to 100 feet (30 m) thick, but locally thicker; locally show evidence of historical movement, especially where incised by washes and along the shores of Lake Powell; larger historical slides and slumps are mapped separately; these landslides are part of an ongoing process that has been active for several million years in this area, though mapped slide materials are probably mostly Pleistocene and Holocene.

Qmsh Historical landslides and slumps (Historical) — Similar to landslides and slumps described above, except show evidence of historical movement; especially prevalent along the shores of Lake Powell where water has saturated and weakened Chinle strata and previously existing landslides; combined with wave action, this has created many unstable slopes that are slumping into the lake, locally creating serious safety hazards (Grundvig, 1980); only large prominent historical landslides and slumps are mapped separately — many Qms deposits and bedrock cliffs and steep slopes also locally show evidence of historical movement; commonly up to 100 feet (30 m) thick, but locally thicker.

Jurassic

Jms Salt Wash Member of Morrison Formation (Upper Jurassic) — Pale- to medium-yellowish-gray, reddish-gray, and greenish-gray, weathering to dark brown, very fine to medium-grained, cross-bedded sandstone, pebble conglomerate, and conglomeratic sandstone, interbedded with minor pale-grayish-green to medium-reddish-brown mudstone and siltstone; forms ledgy cliffs; resistant basal ledge commonly protrudes as an overhanging lip above the ledgy Entrada beds below; only present in map area in one small exposure southwest of Rainbow Bridge where it caps a ridge; this single outcrop is very remote and has not been examined, but float suggests that it may be strongly silicified; regionally, member is about 310 feet (94 m) thick (Peterson and Barnum, 1973), but only the lower about 200 feet (60 m) is preserved within the map area.

J-5 unconformity: Generally a sharp erosional contact; cuts out the upper member of the Entrada Sandstone and overlying units as mapped in areas to the west and southwest (Doelling, 1998; Doelling and Willis, 1999).

Jem Middle member of Entrada Sandstone (Middle Jurassic) — Moderate-reddish-orange to moderate-reddish-brown, medium- to thick-bedded, cross-bedded, calcareous, very fine grained sandstone, interbedded with thin partings of moderate- to dark-reddish-brown siltstone and mudstone, and with scarce very thin beds of grayish-purple bentonitic clay; generally forms red and white banded ledgy cliffs; generally less contorted than lower member; upper contact is unconformable — in the southwestern part of Glen Canyon NRA the middle member is unconformably overlain by the Romana Sandstone, which thins eastward and is cut out about 2 miles (3 km) west of the Rainbow Bridge 7.5’ quadrangle (Peterson and Barnum, 1973); about 360 feet (110 m) thick.

Jel Lower member of Entrada Sandstone (Middle Jurassic) — Pale-reddish-yellow to moderate-reddish-orange, thick-bedded to massive, calcareous, fine-grained sandstone, interbedded with thin partings of moderate reddish-brown siltstone and mudstone; contorted bedding, small internal faults, and complex small-scale folds indicate extensive and complex soft-sediment deformation; fingers and tongues of Entrada Sandstone commonly sag or protrude as pedestals and bulges into the underlying Carmel Formation; forms massive smooth cliffs, rounded bare domes, and broad rolling slickrock swells with common large weathering pits; abundant secondary alteration and bleaching impart mottled, streaked, and banded appearance to outcrops; about 460 feet (140 m) thick (Peterson and Barnum, 1973).

Jc Carmel Formation (Middle Jurassic) — Medium-grayish-red to pale-reddish-gray, earthy weathering, interbedded, fine- to very fine grained sandstone, silty sandstone, siltstone, and mudstone; generally gypsiferous and calcareous; commonly has highly contorted bedding showing a variety of soft-sediment structures produced by loading of the Entrada Sandstone before Carmel strata were lithified; some deformation may be due to dissolution of bedded gypsum, though no bedded gypsum has been recognized in outcrop; forms prominent red ledgy slope between the cliff-forming Entrada and Navajo/Page Sandstones; 100 to 140 feet (30-42 m) thick.

Jp Page Sandstone? (Middle Jurassic) — Moderate-reddish-orange to moderate-reddish-brown, fine-grained, very thickly cross-bedded sandstone; locally has very sparse small angular chert fragments at base; 0 to 100 feet (0-30 m) thick. Citing the locally prominent planar base and the chert fragments, Peterson and Barnum (1973) and Peterson and Pipiringos (1979) suggested the lower contact is the regional J-2 unconformity. Field evidence supporting the presence of an unconformity is tenuous — if the unconformity is not present, then this sandstone interval may actually be part of the Navajo Sandstone.

J-2? unconformity: Peterson and Pipiringos (1979) suggested the contact between the Navajo and Page Sandstones is the regional J-2 unconformity. In most areas typical criteria for identifying an unconformity are missing and the contact is indistinct, while in others the contact is a sharp planar surface, but is difficult to correlate laterally. Thus, the presence of this unconformity is questionable.

Jn, Jnl Navajo Sandstone; limestone beds in Navajo Sandstone (Lower Jurassic) — Pale-yellowish-gray, moderate-reddish-brown, and moderate-reddish-orange, fine- to medium-grained, massive, cross-bedded sandstone; grains are primarily rounded to subrounded, frosted, well-sorted and equant quartz; conspicuously cross-bedded with cross-bed sets that range up to 60 feet (20 m) thick; contains scattered thin lenses of gray sandy limestone, dolomite, and siltstone up to 50 feet thick (15 m) and 2 to 3 miles (3-5 km) long (Jnl) with common algae laminae, ripple marks, and mudcracks; lower contact gradational and intertonguing; forms rounded knobs, buttes, and mesa rims marked by large parallel to conjugate near-vertical joints that are locally mapped and smaller weathering and unloading fractures; 900 to 1100 feet (270-

340 m) thick.

Jk Kayenta Formation (Lower Jurassic) — Moderate- to pale-reddish-brown to reddish-orange, medium to thick lenticularly bedded, cross-bedded, fine- to medium-grained, poorly sorted sandstone, interbedded with very thin to thin-bedded, moderate- to dark-reddish-brown siltstone and muddy sandstone; grains are subangular to subrounded; calcareous cement; locally contains beds of intraformational pebble conglomerate with pebbles of sandstone, siltstone and claystone; forms thick ledges to ledgy cliffs; locally contains sparse fossil wood and thin beds of pinkish-gray limestone; upper and lower contacts gradational and intertonguing; 200 to 240 feet (60-73 m) thick.

JTRw Wingate Sandstone (Lower Jurassic to Upper Triassic) — Pale- to moderate-reddish-orange to reddish-brown, massive, cross-bedded, very fine to fine-grained sandstone; grains are mostly subangular to subrounded and well-sorted; faintly banded, with few partings; in most areas forms a single massive, moderate- to dark-brown, vertical to rounded cliff commonly streaked by vertical dark-brown to almost black desert varnish; locally, especially in strongly weathered areas, horizontal bedding is prominent; upper contact varies from sharp to very gradational and is placed at top of smooth massive cliff and below ledgy beds; locally a few medium to thick beds of orange-brown Wingate-like sandstone are interbedded with red-brown siltstone and fine-grained sandstone of the Kayenta Formation; 260 to 340 feet (80-104 m) thick; fossil evidence indicates the lower part is Late Triassic in age (Lucas and others, 1997).

J-0? unconformity: Pipiringos and O'Sullivan (1978) identified the Wingate-Church Rock boundary as the regional J-0 unconformity. However, Lucas and others (1997) cited evidence that the Wingate has Triassic fossils, and that the contact is gradational, therefore the presence of an unconformity at the Wingate-Church Rock boundary is doubtful.

Triassic

Chinle Formation: The Chinle Formation consists of six members in the San Juan River area (in ascending order): the basal Shinarump Conglomerate Member; Monitor Butte Member; Petrified Forest Member, which locally contains the Moss Back Member as a tongue; Owl Rock Member; and Church Rock Member (Rock Point Formation of Lucas, 1993). The Shinarump and Monitor Butte Members are mapped separately. The remaining four members are herein mapped as one unit called the upper members of the Chinle Formation. Overall, the Chinle is 1195 feet (364 m) thick at Monitor Butte (Stewart and others, 1972a). Lucas (1993) proposed elevating the Chinle Formation to group status and the members to formation status; however, until this change gains wider acceptance, I follow current convention in this mapping (Stewart and others, 1972a; Dubiel, 1994). Lucas and others (1997) indicated that unconformities underlie the Shinarump, Moss Back, and Church Rock Members.

TRcu Upper members of the Chinle Formation (Upper Triassic) — Includes the Church Rock (Rock Point Formation of Lucas, 1993), Owl Rock, Moss Back, and Petrified Forest Members; individual members are recognizable in the field, but are impractical to map separately at this scale; overall, unit forms a slope to ledgy slope that steepens upward to ledgy cliffs just below the massive Wingate Sandstone cliff. The Church Rock Member consists of interbedded reddish-brown to pale-reddish-brown siltstone and fine- to medium-grained sandstone with abundant ripple laminations, mudcracks, and small-scale cross-beds; the sandstone is micaceous; lenticular pebble and rip-up clast conglomerate beds are locally present near base; the Church Rock is similar in color to the overlying Wingate, and forms a steep ledgy slope commonly draped with Wingate rock-fall debris; 38 feet (12 m) thick at Monitor Butte (Stewart and others, 1972a). The Owl Rock Member consists of pale-greenish-gray, pale-purplish-gray, and pale-reddish-gray, calcareous sandstone, mottled limestone, and siltstone; calcrete pedogenic paleosols are abundant; the unit forms a low slope with scattered ledges and is commonly covered by talus; 365 feet (111 m) thick at Monitor Butte (Stewart and others, 1972a). The Moss Back Member is a discontinuous tongue within the Petrified Forest and consists of pale-brownish-yellow, commonly weathering to dark-brownish-gray to yellowish-brown, ledge- and cliff-forming, well-cemented, medium-grained sandstone and pebble conglomerate; Lucas and others (1997) noted that clasts are mostly intrabasinal calcrete and siltstone rip-up fragments; the Moss Back is probably not present within the San Juan River canyon area, but a thin ledge a few feet thick may be present at The Rincon. The Petrified Forest Member consists of strongly variegated purplish-red, greenish-gray, reddish-brown, and gray bentonitic mudstone with sparse lenses of fine-grained sandstone; weathers to form a low non-vegetated "popcorn" slope with locally steep badlands topography; is the major contributor to massive landslides throughout the region; when wet, slopes are extremely slippery; 518 feet (158 m) thick at Monitor Butte (Stewart and others, 1972a).

TRcmn Monitor Butte Member of the Chinle Formation (Upper Triassic) — Mottled to variegated medium-gray to pale-greenish-gray and minor grayish-red to grayish-purple, bentonitic mudstone and sandy mudstone; has lenses of clayey fine-grained sandstone, and thin beds of calcareous shale to coal; weathers to a low soft slope with scattered sandstone ledges; slopes generally have soft "popcorn" weathering; differs from Petrified Forest Member by more uniform greenish-gray color and larger number of sandstone beds; type section is at Monitor Butte where member is 97 feet (30 m) thick (Witkind and Thadden, 1963; Stewart and others, 1972a).

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TRcs Shinarump Conglomerate Member of the Chinle Formation (Upper Triassic) — Pale-yellowish-gray, greenish-gray, to reddish-brown, fine- to coarse-grained sandstone and conglomeratic sandstone, with minor lenses of greenish-gray to reddish-gray mudstone and siltstone; contains silicified and carbonized fossil wood and other plant debris; locally with uranium, copper, and iron mineralization; forms a ledgy cliff with thin slope intervals; lower contact is a regional unconformity; 0 to about 200 feet (0-60 m) thick; 177 feet (54 m) thick at Monitor Butte (Stewart and others, 1972a).

TR-3 regional unconformity: Generally a sharp unconformable contact between the ledgy green-gray to brown lenticular beds of the Chinle Formation and the reddish-brown planar siltstone and sandstone beds of the Moenkopi Formation.

TRm Main body of the Moenkopi Formation (Middle(?) to Lower Triassic) — Moderate-reddish-brown grading up to pale-reddish-brown, thinly laminated to medium-bedded, interbedded, very fine to fine-grained sandstone and siltstone, with scattered thin beds of yellowish-green to greenish-gray claystone; micaceous; discordant gypsum veinlets are abundant; common ripple marks and mud cracks; has rare vertebrate tracks and swimming claw marks; lower part forms ledgy cliff; upper part forms steep slope with scattered ledges; color and grain size distinguish main body from Hoskinnini Member (main body is slightly browner and less orange); 378 feet thick at Monitor Butte (Stewart and others, 1972b); 386 feet (118 m) about 2 miles (3 km) north of Clay Hills Crossing.

TRmh Hoskinnini Sandstone Member of the Moenkopi Formation (Lower Triassic) — Moderate-orangish-pink to moderate-reddish-brown, moderately sorted, mostly very fine to medium-grained sandstone interbedded with silty sandstone beds; outcrops in the Clay Hills Crossing area are very similar in color and erosional habit to the underlying Organ Rock Shale; scattered very coarse sand grains are diagnostic but are not present in every bed; (Hoskinnini Member becomes more cliff-forming northeast of map area and thus is easier to distinguish); in the Nokai Dome area the Hoskinnini is separated from the Organ Rock by the distinctive White Rim Sandstone; upper contact in Clay Hills area is placed at top of a distinctive white to pale-pinkish-brown gypsum bed; Mullens (1960) and Stewart and others (1972b) described the upper contact about 20 feet (6 m) higher; however, this upper interval does not contain the very coarse sand grains and I include it with the main body of the Moenkopi; 68 feet (21 m) thick at Monitor Butte (Stewart and others, 1972b); 110 feet (33 m) about 2 miles (3 km) north of Clay Hills Crossing.

Unconformity

Permian - Pennsylvanian Nomenclature, Age, and Correlation Discussion

Nomenclature, age, and correlation of Pennsylvanian and Permian strata in southeast Utah have been debated for almost 100 years (see Miser, 1924; Baker, 1936; Wengerd and Matheny, 1958; Wengerd, 1963, 1973; Baars and others, 1967; Baars, 1979; Loope and others, 1990; Huffman and Condon, 1993; Condon, 1997; Ritter and others, 2002; Anderson and others, 2003; Stevenson, 2003). I have attempted to apply terms that are most commonly used or that will be most useful to the map user in the field, though I recognize that many arguments exist for alternative nomenclature, ages, and correlations.

The position of the Permian-Pennsylvanian boundary is debatable in southeastern Utah. Condon (1997) indicated that the time boundary is within the lower part of his “lower Cutler beds,” the former Rico Formation of this area, which I map as the upper Honaker Trail Formation. Stevenson (2003) discussed the Pennsylvanian-Permian question, and indicated that recent data indicate that the Halgaito Formation is actually Late Pennsylvanian (Bursumian to Virgillian) in age, and that the time boundary is within the lower part of the Cedar Mesa Formation. For simplicity, I consider the Cedar Mesa as Permian, and underlying beds as Pennsylvanian, though I recognize that the time boundary could be higher or lower in the stratigraphic section.

Permian

Cutler Group: In areas mostly northeast of Glen Canyon National Recreation Area, the Cutler Formation is a single, thick arkosic formation deposited as distal coalescing alluvial fans spread southwest from the Pennsylvanian-Triassic Uncompahgre uplift (located on the Utah-Colorado border northeast of Moab) (Doelling, 2001, 2004). To the southwest, the arkosic facies grades into a series of distinct lithologic units that carry formation names, and thereby the Cutler gains group status. In the San Juan River area, the Cutler Group consists of (descending order): White Rim Sandstone, De Chelly Sandstone (laterally equivalent in position, but possibly not age, to the White Rim), Organ Rock Shale, Cedar Mesa Sandstone, and Halgaito Formation.

Pwr White Rim Sandstone (Lower Permian) — Pale-gray to pale-yellowish-gray, fine- to coarse-grained, cross-bedded sandstone; forms a prominent, nearly white blocky ledge; up to about 30 feet (9 m) thick in Nokai Dome area, but thins eastward and pinches out in subsurface such that is not present in Clay Hills Crossing area outcrops.

Pdc De Chelly Sandstone (outcrop covered by lake mud) (Lower Permian) — Cross-bedded, yellowish-gray, medium-grained sandstone. The De Chelly Sandstone is the prominent cliff-forming unit that forms most of the monuments in Monument Valley of southernmost Utah and northern Arizona. The main body of the De Chelly Sandstone is up to 750 feet (230 m) thick in northern Arizona (Condon, 1997), and thins northwestward to a pinchout about 5 miles (8 km) south of Clay Hills Crossing (along the cliff escarpment southwest of Monument Butte). Mullens (1960) mapped an isolated lens of the De Chelly Sandstone about 30 feet (9 m) thick along the San Juan River about 4 miles (6 km) southwest of Clay Hills Crossing (SE ¼, section 34, T. 40 S., R. 13 E.); this outcrop, which is the only De Chelly Sandstone known in Glen Canyon National Recreation Area, is now covered by Lake Powell mud. The De Chelly Sandstone is in the same stratigraphic position as the White Rim Sandstone to the northwest, but may not be correlative (see discussion in Condon, 1997, p. 26).

Po Organ Rock Shale (Lower Permian) — Interbedded, moderate-reddish-brown to moderate-orangish-pink siltstone, fine-grained quartz to subarkosic sandstone, and sandy shale; has local linear lenses of coarse conglomerate in the upper part of unit near Clay Hills Crossing that erode out in relief and that I interpret to be high-energy stream channel deposits; forms irregular ledges and slopes; 448 feet (137 m) thick near Monitor Butte (Stewart and others, 1972b).

Pcm Cedar Mesa Sandstone (Lower Permian) — Very pale-yellowish-gray, reddish-orange, and reddish-brown, fine-grained, calcareous sandstone locally interbedded with dark-reddish-brown, slope-forming, fine-grained sandstone and siltstone; massive eolian cross-beds with common convolute beds; forms massive cliffs broken by local ledges developed along slope-forming beds; 700 to 1000 feet (210-300 m) thick (Condon, 1997).

Pennsylvanian

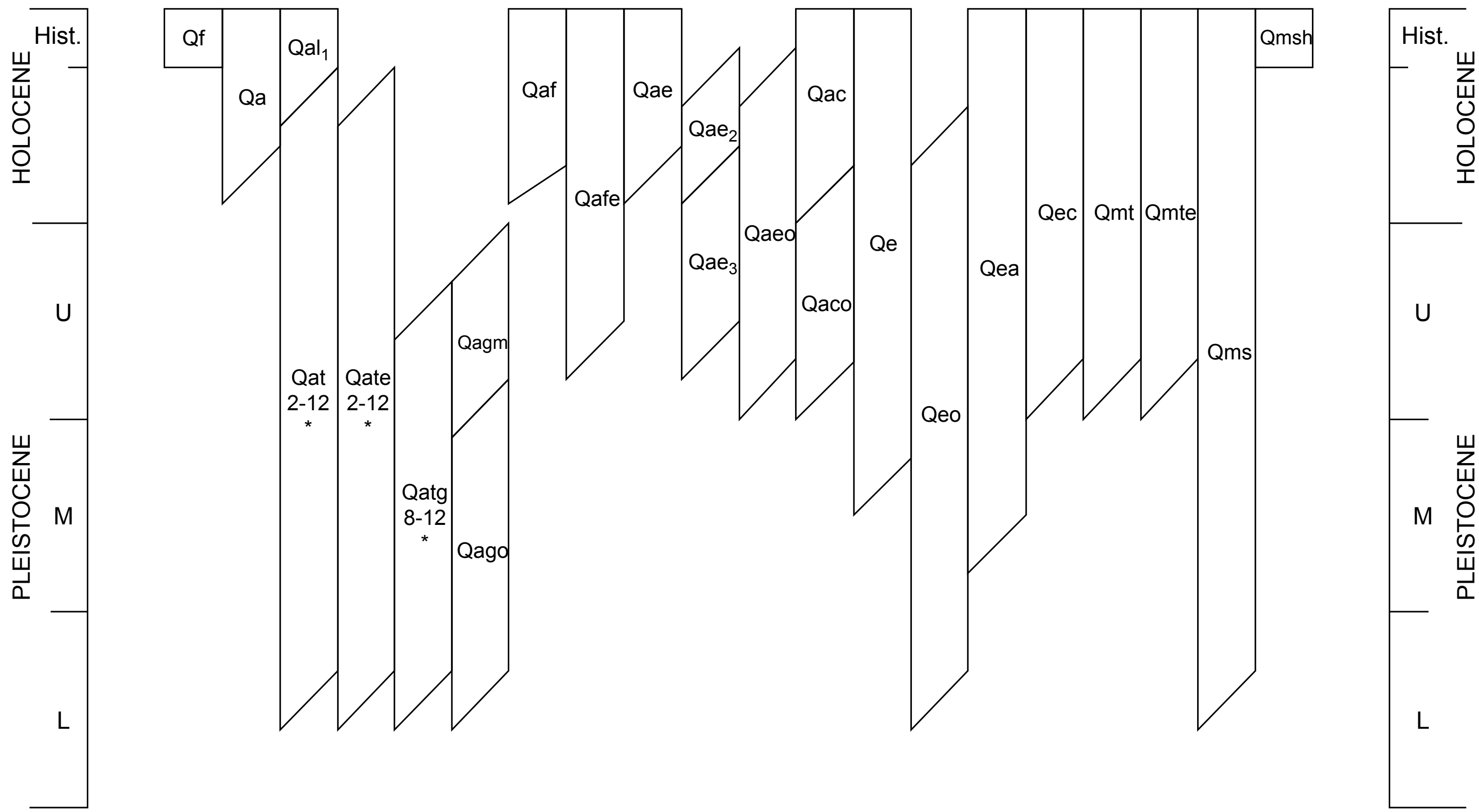
IPhg, IPhgu, IPhgl Halgaito Formation, upper and lower members (Upper Pennsylvanian — Bursumian to Virgillian) — Interbedded reddish-brown, grayish-red, and yellowish-red, very fine to medium-grained sandstone, dark-red micaceous siltstone, with thin beds of gray cherty fossiliferous limestone and dolomite in the lower part; mapped as two informal members, the lower (IPhgl) includes the thin but prominent ledges of limestone and dolomite, while the upper (IPhgu) has locally very minor to no carbonate beds; gains more limestone beds in subsurface toward northwest as it grades into the Elephant Canyon Formation (Condon, 1997; Stevenson, 2003); northward, in the subsurface, the formation tongues into the arkosic facies of the Cutler Formation; formation is 465 feet (142 m) thick at Johns Canyon (Condon, 1997); Condon (1997) chose to call this interval part of the "lower Cutler beds" but still used the term "Halgaito" on figures and correlation diagrams; lower member about 380 feet (116 m) thick; upper member about 60 to 90 feet (18-27 m) thick.

IPhtu, IPhtl Honaker Trail Formation, upper and lower members (Upper Pennsylvanian — Virgillian to Desmoinesian) — Cyclically interbedded pale-gray to pale-yellowish-gray limestone, pale-yellowish-brown to pale-yellowish-gray siltstone to very fine grained sandstone, and medium- to very dark gray to black organic shale; overall outcrop appearance is similar to the Paradox Formation but forms more ledges and smaller cliffs; dark-gray to black organic shale is primary slope-forming lithology in lower part of formation, whereas reddish-brown very fine grained sandstone, siltstone, and mudstone become more abundant in slopes of the middle and upper part of the formation; the upper contact is placed at the top of the highest prominent laterally continuous limestone bed, though thin discontinuous limestone beds are present for an additional 40 to 50 feet (12-15 m) up into the Halgaito Formation; the highest prominent limestone bed has been referred to as the Shaffer bed though it probably does not correlate with the Shaffer limestone of the Moab area (Wengerd, 1963; Ritter and others, 2002); a prominent ledge-forming sandstone bed informally called the Goodrich Sandstone directly overlies the upper limestone throughout most of the map area, forming a distinctive double-ledge with the formation contact between the two ledges; 715 feet (218 m) thick (Wengerd, 1963).

The Honaker Trail Formation is herein mapped as informal upper (IPhtu, about 160 to 180 feet [49-55 m] thick) and lower (IPhtl, about 535 to 555 feet [163-169 m] thick) members with the contact placed at the gradational change from gray and black shale slope-forming intervals; the contact is gradational and the lower member contains minor red beds near the upper contact. The contact between the upper and lower members corresponds to Condon's (1997) recommended top of the Honaker Trail Formation and is more prominent on drill logs that clearly depict the change from the gray shales to red beds. The generally abandoned Rico Formation (see discussion in Condon, 1997) corresponds to the combined upper member of the Honaker Trail Formation (IPhtu) and lower member of the Halgaito Formation (IPhgl) as mapped herein. The upper Honaker Trail and entire Halgaito approximately correspond to Condon's (1997) "lower Cutler beds."

IPp Paradox Formation (Middle Pennsylvanian — Desmoinesian) — Cyclically interbedded pale-gray to pale-yellowish-gray limestone, pale-yellowish-brown to pale-yellowish-gray siltstone to very fine grained sandstone, and medium to very dark gray to black organic shale; limestone beds are shaley lime mudstone, spiculiferous wackestone, fossiliferous and peloidal wackestone and packstone, algal boundstone, and cross-bedded ooid grainstone; sandstone is planar to trough cross-bedded and has abraided fossil material; shale is fossil-poor, laminated to thinly laminated, highly organic, and locally sulfurous; fossils include crinoids, bryozoans, brachiopods, fusulinids, corals, foraminifers, conodonts, and fish fragments; contains scattered distinctive algal boundstone mounds composed of phylloid algal plates (appear like mounds of crushed potato chips); cycles are typically 6 to 20 feet (2-6 m) thick; mapped in core of Cedar Mesa anticline in stratigraphically deepest part of San Juan River canyon; base of formation is below river level and not exposed; upper contact is placed at the top of a massive blocky cliff known as "The Horn limestone" that forms the most recognizable horizon in the canyon and is composed of massive blocky limestone with a thin interbedded sandstone in the upper part, and at the base of a sandy dolomitic limestone and dolomite interval that has a distinctive grayish-yellow color and is referred to informally as “Old Yeller”; formation is divided into four informal stages (not mapped separately) each bounded by dark gray organic shale beds (from lowest to highest — Barker Creek, Akah, Desert Creek, and lower Ismay); 583 feet (178 m) thick at Honaker Trail (Wengerd, 1963); outcrops of formation at Honaker Trail are some of the most studied Pennsylvanian rocks in the state (notable studies include Miser, 1924; Wengerd and Strickland, 1954; Wengerd and Matheny, 1958; Pray and Wray, 1963; Wengerd, 1963, 1973; Stevenson, 2003; Ritter and others, 2002).

Underlying rocks: Underlying rocks of the San Juan River area include part of the Paradox Formation and the Pennsylvanian Pinkerton Trail and Molas Formations; the Mississippian Leadville or Redwall Formation; the Mississippian and Devonian Ouray Limestone; the Devonian Elbert (including the basal McCracken Sandstone) and Aneth Formations; the Cambrian Lynch Dolomite, Muav Formation, Bright Angel Shale, and Ignacio Quartzite; and Proterozoic gneisses and schists.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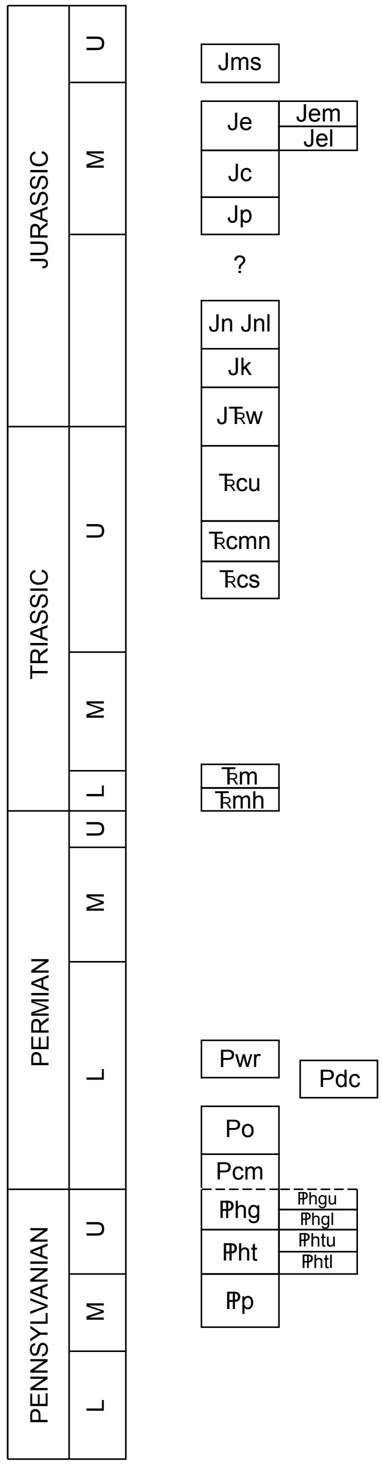
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